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DYNAMIC STABILITY OF PLATES RESTING ON ELASTIC FOUNDATION

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ABSTRACT

An accurate closed form solution to predict the dynamic stability behaviour of a square plate resting on an elastic foundation subjected to edge periodic loads, has been obtained. The Energy method is applied to solve the dynamic stability problem. A Simple trigonometric function is used to analyse characterize the deflection. Numerical results are presented using proper non-dimensional parameters with varying elastic foundation. The consequences of the foundation on the dynamic stability boundaries is brought out, highlighting the employment of the specific non-dimensional parameters applied in the present work. The effect of the elastic foundation parameter on the regions of dynamic stability is brought in this work.

KEYWORDS: Dynamic Stability, Periodic Loads, Square Plate & Elastic Foundation

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Original Article

1. INTRODUCTION

Prediction of dynamic stability regions of structural members, like beams, plates and shells subjected to periodic loads is an important input for the structural engineers. Analyzing the dynamic stability behaviour of structural members subjected to periodic in-plane loads is an important phase for the design engineers. This analysis is done to have a clear understanding of the members under various static and dynamic loading conditions. Therefore dynamic instability has created the way for direct structural engineering applications. Plates on elastic foundation with various combinations of boundary conditions are mostly encountered in Aerospace machinery, Mechanical equipments, civil structures, containers, ships and also offshore structures. They are mostly subjected to in plane dynamic loads. The dynamic instability of plates has received deep attention in recent years and the behaviour of thin plates has been studied by many researchers. During the last two decades considerable advances have made in the applications of numerical techniques to analyze and understand the basic structural elements. The dynamic stability behaviour of structural members is well discussed in the good work of Bolotin [1]. Detailed reviews on dynamic stability of plates with in-plane periodic loads are presented by Jagadish [2]. Hutt and Salama [3] studied the problem of dynamic instability of plates and bars by Finite Elements. Krajcinovic and Herrmann [4] used an integral equation technique to solve numerical solutions of Dynamic Stability problem for isotropic plates. Takahashi and Konishi [5] analyzed the dynamic stability of plates analytically. Chen and Yang [6] studied the dynamic stability of laminated composite plates by FEM. Sassi [7] analyzed the behaviour of plates under combined parametric and forcing excitation. Raju and Rao [8] examined the thermal-post buckling of a circular plate.

Some recent studies in this topic for plates subjected to periodic loading can be seen in Ramachandra and Sarat Kumar [9] shown that those non-dimensional parameters used it can be derived and demonstrated the existence of unique dynamic stability curves for commonly used structural members. B. Subba Ratnam *et al.,* [10] derived the formula for dynamic stability of a square plate with constant compressive and periodic loads by analytically.

In this work, to develop a simple closed form solution to predict the dynamic instability boundaries. Elegant, simple and accurate closed form analytical solutions to predict the dynamic stability regions of a square plate subjected to an in plane periodic edge loads are very attractive for design engineers. An attempt is made, in this paper, to provide such a closed form solution for square plate resting on an elastic foundation. In this work an energy method is used to develop a simple closed form solution to predict the dynamic instability behavior of the simply supported square plate, using exact trigonometric admissible function to represent the transverse deflection, as given by Leissa [9]. The main contribution in the proposed work is to investigate the effect of elastic foundation on the boundaries of dynamic stability, is brought in this paper.

2. FORMULATION

Case (i): Dynamic Stability Equation without Elastic Foundation

When the plate is subjected to uniform edge in-plane periodic load N_x (t) as shown in the figure1.

The periodic load, as,

$$N_x(t)= N_s+N_t \cos\theta t = (\alpha \pm \beta \cos\theta t)N_{cr} \tag{1}$$

where α is static load factor $=\frac{N_s}{N_{cr}}$, β is the dynamic load factor = $\left(\frac{N_t}{N_{cr}}\right)$, N_s static load factor, N_t is a time dependent load, N_{cr} is the buckling/critical load, θ is the applied radian frequency, t indicates time.

For a square plate of Length A and breadth B with constant thickness t, the strain energy U, the work done by external load W and kinetic energy T is given by,

$$U=\frac{D}{2}\int_0^A\int_0^B\left[k_x^2+k_y^2+2\vartheta\, k_x k_y+\frac{1-\vartheta}{2}k_{xy}^2\right]dxdy \tag{2}$$

$$W=\frac{N_x(t)}{2}\int_0^B\int_0^A\left(\frac{\partial w}{\partial x}\right)^2 dxdy \tag{3}$$

$$T=\frac{\rho t\omega^2}{2}\int_0^B\int_0^A w^2\, dxdy \tag{4}$$

with,

$$k_x^2=\frac{-\partial^2 w}{\partial x^2}, k_y^2=\frac{-\partial^2 w}{\partial y^2}, k_{xy}=-2\frac{\partial^2 w}{\partial x\partial y} \tag{5}$$

where w is the lateral displacement, ρ is the mass density, ω is the radian frequency of the plate N_x(t) and D is the plate flexural rigidity, E is the young's modulus and ϑ is the poisons ratio.

The admissible transverse displacement w in terms of m and n, which are the number of half-waves in the x and y coordinates respectively, is assumed to be of the form,

$$w = a\sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right) \tag{6}$$

where a is the undetermined coefficient. The displacement distribution assumed for w is exact for the simply supported boundary conditions for both the vibration and buckling problems.

The total potential energy Π of the plate is given by,

$$\Pi = U\text{-}W\text{-}T \tag{7}$$

$$\Pi = \frac{D}{2}\int_0^A\int_0^B\left[k_x^2 + k_y^2 + 2\vartheta\, k_x k_y + \frac{1-\vartheta}{2}k_{xy}^2\right]dxdy - \frac{\gamma N_x}{2}\int_0^B\int_0^A\left(\frac{\partial w}{\partial x}\right)^2 dxdy - \frac{N_x(t)}{2}\int_0^B\int_0^A\left(\frac{\partial w}{\partial x}\right)^2 dxdy \tag{8}$$

where U, W, T are strain energy, kinetic energy and potential energy due to work respectively. In Rayleigh- Ritz method, the total potential energy is minimized with respect to undetermined coefficient a, as

$$\frac{\partial\pi}{\partial a} = \left(\frac{\partial}{\partial a}\right)(U - W - T) = 0 \tag{9}$$

which yields, after simplification of Equation (9) by neglecting the terms for W, an expression for the frequency parameter,

$\lambda_f = \frac{\rho t \omega^2 A^4}{D}$ is obtained as,

$$\lambda_f = \pi^4\left(m^2 + n^2\frac{A^2}{B^2}\right)^2 \tag{10}$$

where λ_f is the frequency parameter

Similarly by neglecting T then the dynamic stability equation, then equation becomes as

$$\frac{\partial}{\partial a}(U - W) = 0$$

The expression for the λ_b buckling load parameter,

$$\lambda_b = \frac{m^2 + n^2\left(\frac{A^2}{B^2}\right)}{m^2 + \gamma n^2\left(\frac{A^2}{B^2}\right)} \tag{11}$$

Substituting the energies U, T and W after simplification the dynamic stability equation in the non-dimensional form as,

$$1 - \frac{\left\{\left(\alpha \pm \frac{\beta}{2}\right)m^2 + \gamma n^2\frac{A^2}{B^2}\right\}}{\left(m^2 + \gamma n^2\frac{A^2}{B^2}\right)} - \frac{\theta^2}{4\omega^2} = 0 \tag{12}$$

For square plate (A/B=1) for the first mode of buckling and vibration (m=n=1) and γ=0 for uni-axial load then the equation becomes

$$1 - \left(\alpha \pm \frac{\beta}{2}\right) - \frac{\theta^2}{4\omega^2} = 0 \tag{13}$$

Defining Ω,

$$\Omega = \frac{\theta}{\omega} = 2\sqrt{1 - \left(\alpha \pm \frac{\beta}{2}\right)} \tag{14}$$

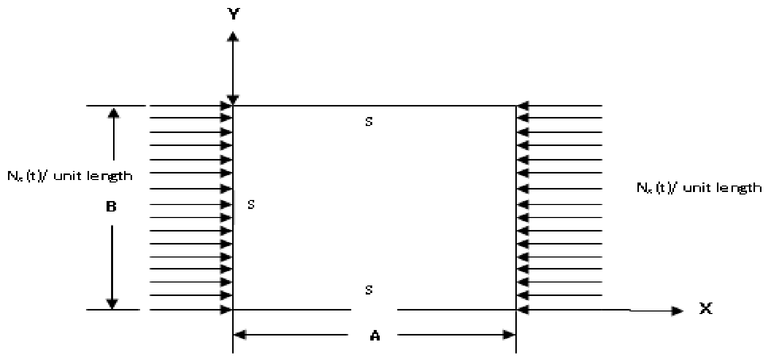

Figure 1: A Simply Supported Square Plate under Periodic Load.

Above Equation can be treated as a dynamic stability solution containing the physically identifiable non-dimensional parameters. This equation can be treated as dynamic stability solution for the mentioned loading condition.

Case (ii): Dynamic Stability Equation with Elastic Foundation

The mathematical formulation, to evaluate the dynamic stability boundaries, for an isotropic square plate on elastic foundation (Winkler type) subjected to uniaxial edge periodic load N(t), as shown in figure2, the total potential energy π is given, by

$$\Pi = U + U_F - W - T \tag{15}$$

where

$$U_F = \int_0^A \int_0^B w^2 \, dxdy$$

$$\frac{\partial \pi}{\partial a} = \left(\frac{\partial}{\partial a}\right)(U + U_F - W - T) = 0 \tag{16}$$

This yields, after simplification of the above equation by neglecting the term W, an expression for frequency parameter,

$$\lambda_f = \left\{\left(m^4 + n^4 \frac{A^4}{B^4}\right) + \gamma_F\right\} \tag{17}$$

for m = n = 1

$$\lambda_f = \left\{\left[1 + 2\left(\frac{A^4}{B^4}\right) + \left(\frac{A^4}{B^4}\right)\right] + \lambda_F\right\}\pi^4 \tag{18}$$

for square plate A/B = 1

$$\lambda_f = [4 + \gamma_F] + \pi^4 \tag{19}$$

Similarly, by neglecting the kinetic energy term *T* in the equation the expression for buckling load parameter

$$\lambda_b = 4 + \gamma_F \tag{20}$$

Defining Ω=,

$$\frac{\theta}{\omega} = \frac{\left[1 + \left(\frac{A^2}{B^2}\right)\right]}{\sqrt{1 + \frac{A^4}{B^4} + \gamma_F}} \tag{21}$$

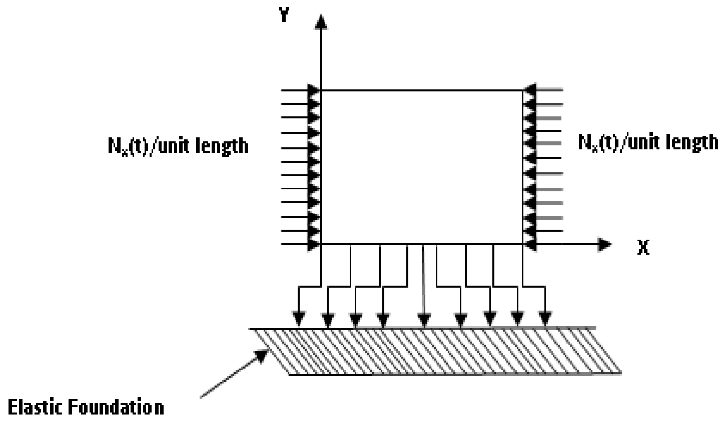

Figure 2: A Simply Supported Square Plate with Elastic Foundation Subjected to Periodic Loads.

If m = n = 1, then

$$\Omega = \frac{\theta}{\omega} = \frac{4}{4+\gamma_F} = 2\sqrt{1-\left(4 \pm \gamma_F\right)\left(\alpha \pm \frac{\beta}{2}\right) + \frac{\gamma_F}{8}} \tag{22}$$

The above equation can be treated as the dynamic stability solution containing the physically identifiable non-dimensional parameters. After simplification,

$$\frac{\theta}{\omega} = 2\sqrt{(1-\alpha)(1 \pm \mu) + \frac{\gamma_F}{4}} \tag{23}$$

Using the equation (23) the dynamic stability regions of the square plate can be evaluated with vaying α and β for different values of elastic foundation stiffness parameter.

3. NUMERICAL RESULTS AND DISCUSSIONS

The non-dimensional formula developed here in the above section is much simple to evaluate the dynamic stability regions of a square plate. In the non dimensional form, the characteristic values of the plate such as fundamental frequency and the static bucking load parameters do not appear explicitly.

Table 1 shows the values of instability boundaries Ω_1 and Ω_2 for the value of β varying from 0 to 1.0 for the simply supported isotropic square plate with uniform uniaxial in-plane edge periodic load i.e. (γ= 0.0) for α = 0.0, 0.25 and 0.5. The dynamic instability regions of the square plate are given in L.S Ramachandra and Sarat Kumar [9] and the present results for γ= 0.0 (Uniform uniaxial edge periodic load) are deduced from the dynamic stability formulae Equation(14), derived here, for □ = 0.0 and 0.6 as is given in tables 2 and 3 respectively. The very good agreement between the two results strongly indicates the usefulness of the simple dynamic stability formula, developed in the present work.

Tables 4 to 7 shows the values of instability boundaries for Ω_1 and Ω_2 for the value of β varying from 0 to 1.0 for the simply supported isotropic square plate with uniform uniaxial in-plane edge periodic load for α = 0.0, 0.5 and 0.8, for the γ= 1 to 4. It is observed that from the tables and figures the instabilty regions are decreasing with increase in elastic foundation parameter and shifts away from the vertical axis. This shows the plate is more stable with elastic foundation.

Table 1: Variation of Ω_1 and Ω_2 for Square Plate Subjected to Uniaxial Periodic Load

β	α = 0.0		α = 0.25		α = 0.5	
	Ω_1	Ω_2	Ω_1	Ω_2	Ω_1	Ω_2
0.0	2.0000	2.0000	1.7320	1.7320	1.4142	1.4142
0.1	1.9493	2.0493	1.6733	1.7888	1.3416	1.4832
0.2	1.8973	2.0976	1.6124	1.8439	1.2649	1.5491
0.3	1.8473	2.1447	1.5491	1.8973	1.1832	1.6124
0.4	1.7888	2.1908	1.4832	1.9493	1.0954	1.6733
0.5	1.7320	2.2360	1.4142	2.0000	1.0000	1.7320
0.6	1.6733	2.2803	1.3416	2.0493	0.8944	1.7888
0.7	1.6124	2.3237	1.2649	2.0976	0.7745	1.8439
0.8	1.5491	2.3664	1.1832	2.1447	0.6324	1.8973
0.9	1.4832	2.4083	1.0954	2.1908	0.4472	1.9493
1.0	1.4142	2.4493	1.0000	2.2360	0.0000	2.0000

Table 2: Variation of Ω_1 and Ω_2 for Square Plate Subjected to Uniaxial Periodic Load for α = 0

β	Present Formula		Ref.[9]*	
	Ω_1	Ω_2	Ω_1	Ω_2
0.0	39.4801	39.4801	39.09	39.09
0.2	37.4527	41.4066	37.27	40.91
0.4	35.3109	43.2463	35.22	42.73
0.6	33.0309	45.0131	32.72	44.54
0.8	30.5792	46.7127	30.68	46.36
1.0	27.9163	48.3491	27.29	47.72

*Values are read from the graph [9]

Table 3: Variation of Ω_1 and Ω_2 for Square Plate Subjected to Uniaxial Periodic Load for α = 0.6

β	Present Formula		Ref.[9]*	
	Ω_1	Ω_2	Ω_1	Ω_2
0.0	24.9693	24.9693	25.03	25.03
0.1	23.3563	26.4831	23.45	26.36
0.2	21.6231	27.9163	21.51	27.93
0.3	19.7393	29.2783	19.81	29.27

*Values are read from the graph [9]

Table 4: Variation of Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F=1

β	α = 0.0		α = 0.5		α = 0.8	
	Ω_1	Ω_2	Ω_1	Ω_2	Ω_1	Ω_2
0.0	2.2360	2.2360	1.7320	1.7320	1.3416	1.3416
0.1	2.1908	2.2803	1.7029	1.7606	1.3266	1.3564
0.2	2.1447	2.3237	1.6733	1.7888	1.3114	1.3711
0.3	2.0976	2.3664	1.6431	1.8165	1.2961	1.3856
0.4	2.0493	2.4083	1.6124	1.8439	1.2806	1.4000
0.5	2.0000	2.4494	1.5811	1.8708	1.2649	1.4142
0.6	1.9493	2.4899	1.5491	1.8973	1.2489	1.4282
0.7	1.8973	2.5298	1.5165	1.9235	1.2328	1.4422
0.8	1.8489	2.5690	1.4832	1.9493	1.2165	1.4560
0.9	1.7888	2.6076	1.4491	1.9748	1.2000	1.4696
1.0	1.7320	2.6457	2.0000	1.4142	1.1832	1.4832

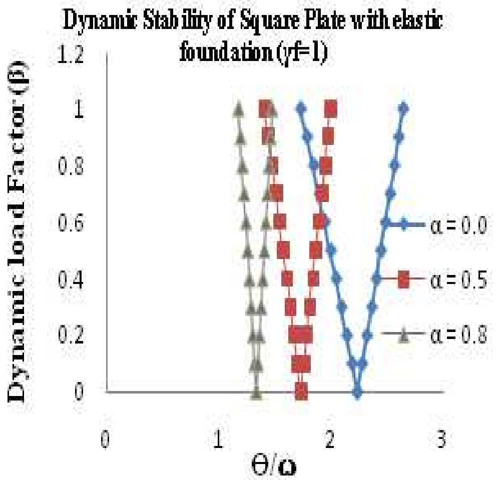

Figure 3: Dynamic Stability Curves for Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F=1.

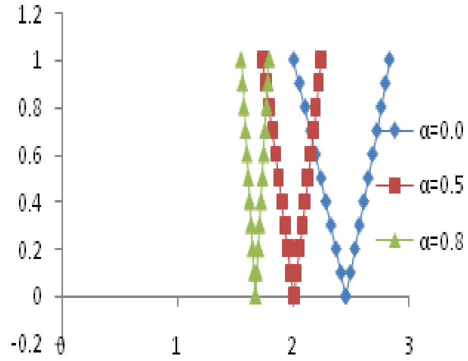

Figure 4: Dynamic Stability Curves Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F =2.

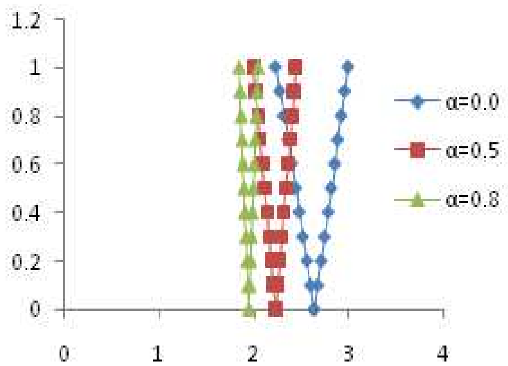

Figure 5: Dynamic Stability Curves for Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F=3.

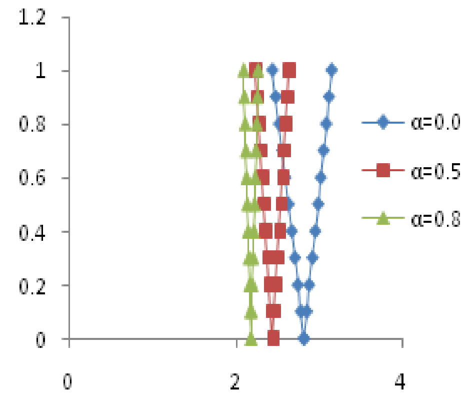

Figure 6: Dynamic stability Curves for Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F=4.

Table 5: Variation of Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F =2

β	α = 0.0		α = 0.5		α = 0.8	
	Ω_1	Ω_2	Ω_1	Ω_2	Ω_1	Ω_2
0.0	2.4494	2.4494	2.0000	2.0000	1.6733	1.6733
0.1	2.4083	2.4899	1.9748	2.0248	1.6852	1.6613
0.2	2.3664	2.5298	1.9493	2.0493	1.6492	1.6970
0.3	2.3237	2.5690	1.8973	2.0736	1.6370	1.7088
0.4	2.2803	2.6076	1.8708	2.0976	1.6124	1.7204
0.5	2.2360	2.6457	1.8439	2.1213	1.6124	1.7320
0.6	2.1908	2.6832	1.8165	2.1447	1.6000	1.7435
0.7	2.1447	2.7202	1.7606	2.1908	1.5874	1.7549
0.8	2.0976	2.7568	1.7320	2.2360	1.5748	1.7663
0.9	2.0493	2.7928	1.7606	2.2135	1.5620	1.7776
1.0	2.0000	2.8284	1.7320	2.2360	1.5491	1.7888

Table 6: Variation of Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F=3

β	α = 0.0		α = 0.5		α = 0.8	
	Ω_1	Ω_2	Ω_1	Ω_2	Ω_1	Ω_2
0.0	2.6457	2.6457	2.2360	2.2360	1.9493	1.9493
0.1	2.6076	2.6832	2.2135	2.2583	1.9390	1.9599
0.2	2.5690	2.7202	2.1908	2.2803	1.9287	1.9697
0.3	2.5298	2.7568	2..1679	2.3021	1.9183	1.9798
0.4	2.4899	2.7928	2.1447	2.3237	1.9078	1.9899
0.5	2.4494	2.8284	2.1213	2.3450	1.8973	2.0000
0.6	2.4083	2.8635	2.0976	2.3664	1.8867	2.0099
0.7	2.3664	2.8982	2.0736	2.3874	1.8761	2.0199
0.8	2.3237	2.9325	2.0493	2.4083	1.8654	2.0297
0.9	2.2803	2.9664	2.0248	2.4289	1.8547	2.0396
1.0	2.2360	3.0000	2.0000	2.4494	1.8483	2.0493

Table 7: Variation of Ω_1 and Ω_2 for Square Plate with Elastic Foundation γ_F=4

β	α = 0.0		α = 0.5		α = 0.8	
	Ω_1	Ω_2	Ω_1	Ω_2	Ω_1	Ω_2
0.0	2.8284	2.8284	2.4494	2.4494	2.1908	2.1908
0.1	2.7928	2.8635	2.4289	2.4899	2.1817	2.2000
0.2	2.7568	2.8982	2.4083	2.5099	2.1725	2.2090
0.3	2.7202	2.9392	2.3874	2.5298	2.1633	2.2181
0.4	2.6832	2.9664	2.3664	2.5495	2.1540	2.2271
0.5	2.6457	3.0000	2.3452	2.5495	2.1447	2.2360
0.6	2.6076	3.0331	2.3237	2.5690	2.1354	2.2449
0.7	2.5690	3.0659	2.3021	2.5884	2.1260	2.2538
0.8	2.5298	3.0983	2.2803	2.6076	2.1166	2.2627
0.9	2.4899	3.1304	2.2583	2.6267	2.1071	2.2715
1.0	2.4494	3.1622	2.2360	2.6457	2.0976	2.2803

4. CONCLUSIONS

Accurate closed form solutions are obtained to predict the dynamic stability boundaries of the simply supported square plate resting on an elastic foundation subjected to uniform in-plane edge periodic loads. Simple one term standard trigonometric admissible function that satisfies all the boundary conditions is used to obtain the solution employing the energy method. It is noted here, by increasing the elastic foundation parameter, the regions of instability decreases and shift towards the vertical axis using a physically recognizable dynamic load factor (β).

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